Performance Analysis of Video Transmission Over IEEE 802.11n Wireless Networks

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***Abstract*—Multimedia services over wireless networking environment have become increasingly popular, especially for the online video streaming services and applications. This research analyzes the performance of video transmission over IEEE 802.11n in term of throughput, delay, and peak signal to noise ratio (PSNR) to find the characteristics of video streaming over a wireless network and to also propose a method to improve the transmission performance. Videos on YouTube from various categories were employed as a video dataset for evaluation in this research. Video splitting, video blending, and optimized reconstruction were proposed as video pre-processing and video reconstruction techniques used for enhancing the transmission usage and the quality of the transmitted video. Results indicated that the approach can improve the PSNR to the desired level.**

***Index Terms*—IEEE 802.11n; Video Transmission; Video Preprocessing; Video Reconstruction; Wireless Network.**

I. Introduction

Online video streaming is growing at an outstanding rate. Statistical information indicated that there are more than one billion users on YouTube [1-2]; time spent viewing online is hundreds of millions of hours on YouTube each day; and, in every minute, 300 hours of video are uploaded to YouTube. In order to acquire smooth streaming video with high quality pictures and sound, high network bandwidth is required. Note that high quality video transmission could be a source of network congestion. One possible solution is to reduce the quality of transmitting video which is unpleasant for end users.

In addition, with the advanced wireless technology, people can watch video on their mobile and wireless devices. Transmitting high quality video over a wireless network is a very challenging problem due to the characteristics of wireless network, such as limited bandwidth, connection loss, packet loss, high error rate, fluctuation of channel condition, and heterogeneous and dynamic wireless uses [3]. Different types of video coding standards, e.g., MPEG, HEVC, RealVideo, and VP, have been developed to support multimedia applications and video transmission over wireless channels [4].

In particular, for years, MPEG-4 [5-6] has been one of the well-known video coding formats and in capable of compressing images at high efficiency which also supports high-definition video. This version absorbs many features of their formers, e.g., MPEG-1 and MPEG-2, and other related standards, which has been adopted to many applications. Various techniques used in image coding, motion estimation, error resilient, and frame reconstruction were also developed to improve the quality of video transmission with limited network bandwidth including other network transmission constraints.

In this research, the characteristics of video streaming over IEEE 802.11n were analyzed to find a promising method to enhance the quality of video transmitted over a wireless network. This research also proposes video splitting, video blending, and optimized reconstruction as video pre-processing and video reconstruction techniques created for improving video transmission performance. The performance evaluation results confirmed that these techniques can improve the peak signal to noise ratio (PSNR).

This research article is organized as follows. Section 2 provides background information of this research and related work. The experimental process and methods including experimental setup are presented in Section 3. Section 4 explains our techniques optimally designed for video transmission. Section 5 discusses the results obtained from performance evaluation. The conclusions and future work are also presented in the last section.

II. Literature Review

Video coding standards are primarily designed to increase the ability to minimize bit rate required for presenting video content at a certain level of video quality, alternatively, to maximize video quality within an available bit rate [4]. In addition, various video coding standards have been proposed for different purposes. For example, H.264/AVC, also called MPEG-4 AVC or MPEG-4 Part 10, was designed for supporting video streaming with high compression efficiency and robustness against errors over a heterogeneous network [7].

There are many attempts to enhance the performance of transmitting video in different formats, especially those with high compression efficiency, over a wireless network. In 2011, Hsiao et al. presented a number of issues, existing solutions to H.264 video transmissions over wireless networks, and open research issues, including the improvement of H.264 video transmission efficiency [7].

Zheng et al. proposed an adaptive frame aggregation scheme, which applied MAC Protocol Data Unit Aggregation (A-MPDU) and adaptive optimal subframe size to channel conditions in order to enhance the performance of video transmission over IEEE 802.11n WLAN [8]. The simulation results showed that the frame aggregation mechanism can improve the throughput performance when the number of subframe aggregated in one MAC frame was increased; however, the approach increased the end-to-end delay and the optimal subframe size still had a minimal side-effect on the video quality [8].

In 2013, Adeyemi-Ejeye and Walker [9] evaluated the performance of ultra-high definition video (Ultra HD) in terms of Structural Similarity Index Metric (SSIM), packet delay, and packet loss to characterize the wireless network specifications so as to achieve higher frequency bands and throughput. The results from both simulations and experiments indicated that the IEEE 802.11n operated on 5GHz band can support 4K Ultra HD video at lower bitrate and subsampling [9]. However, in case of 8K Ultra HD video, higher bite rate is then required.

Recently in 2014, Memon et al. [10] performed the evaluation of video transmission with PSNR as its main metric using EvalVid framework to measure video quality perspective including the investigation of throughput and packet delay; however, there is no consideration of congested link. It should be noted that the EvalVid tool was first proposed by Ke et al. [10] for the purpose of video streaming transmission evaluation, especially on the focus of video processing and encoding regardless of the networking media, i.e., IEEE 802.11n.

In this research, we evaluated the performance of MPEG-4 YouTube video transmission characteristics over IEEE 802.11n in terms of throughput, delay, and PSNR; and then presented the diverse characteristics of video category. The results were employed to create video pre-processing and video reconstruction techniques to finally improve the transmission performance.

III. Empirical Study

In this scheme, there are three main components for our evaluation testbed: Video Pre-processing, Video Transmission, and Video Reconstruction. It should be noted that the input video is acquired from YouTube which is then converted to YUV formats using FFmpeg tools (www.ffmpeg.org). Therefore, the generated MPEG-4 will be separated to I, P, and B to be suitably used for video transmission using NS2 simulators [11] together with IEEE 802.11n modules [12]. After the transmission, the in-completed video will be recovered in case of packet loss to be ready for further analysis.

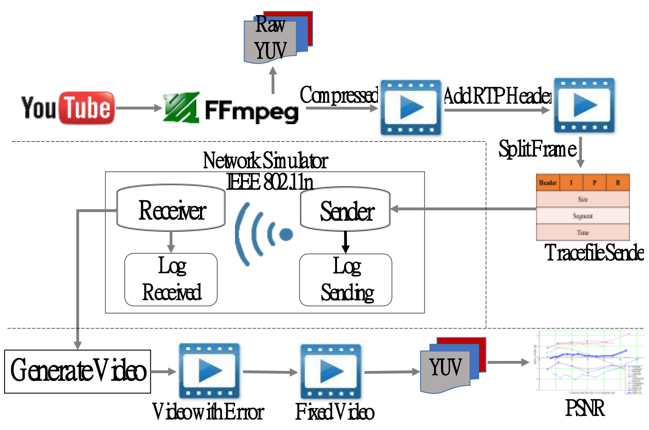

Figure 1: An overview of video transmission platform over IEEE 802.11n

A. Video Pre-processing

This stage is used to properly prepare the video trace from YouTube (www.youtube.com) [1-2] before feeding to the actual transmission on NS2 simulators. In this evaluation, this research selected EvalVid platform [13-17] as the baseline to construct the video trace for simulators as well as video reconstruction process. Here, there are five phases as follows:

Video Acquisition: At this phase, the video dataset was retrieved from YouTube by utilizing the third party software, i.e., www.108clip.com. Then, the video was adjusted to 30 seconds in length by using Movie Maker (built-in Microsoft Windows) in QIF (352×288) formats using Handbrake (handbrake.fr).

It should be noted that there are 16 categories for the characteristic analysis based on www.imdb.com/genre, one of the largest movie datasets, namely, Music, Comedy, Film and Entertainment, Gaming, Beauty and Fashion, From TV, Automotive, Animation, Sports, How-to and DIY, Tech, Science and Education, Cooking and Health, Causes and Non-profits, News and Politics, and Lifestyle. As examples shown in Figure 2, for reproducibility, it is worth noting that the trace is also available at web.kku.ac.th/chakso/video-dataset/index.html.

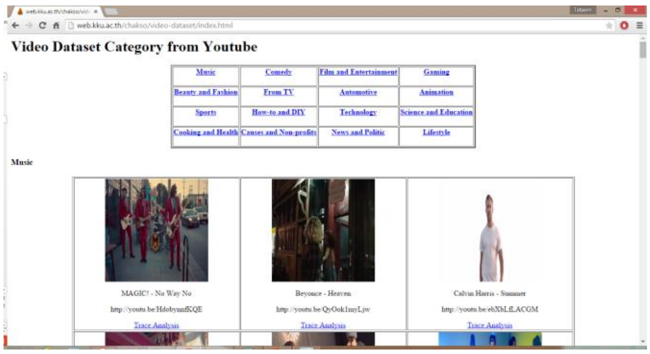

Figure 2: Video trace category: *web.kku.ac.th/chakso/video-dataset/index.html*

Video Transformation: The key function of this phase is used to convert YouTube video to YUV 420p formats, and "FFmpeg" was used for serving the purpose.

Video Compression: After the transformation, "xvid_encraw" was selected to adjust a proper frame size (members.optusnet.com.au/squid_80/sources/xvid_encraw_src.zip), i.e., 352×288 at 30 frame per second (fps).

Video Packetization: This phase is used to prepare Real-time Transport Protocol (RTP) packet with 1024 as the maximum packet size including RTP header. Here, "MP4box" was used for that purpose (gpac.wp.mines-telecom.fr/mp4box). It should be noted that in the actual transmission, additional headers, UDP and IP, will result into 1024+8+20 = 1052 bytes in total.

Video Frame Separation: At the final phase, the video transmission trace was then generated for IEEE 802.11n simulators using NS2. "mp4trace" was used to construct this trace [13-17]. Note that the trace file consists of a sequence of video frame (I, P, and B), ID, Video Frame Format, Frame Size, Number of Frames, and Transmitted Time Stamp, such as "1 I 14364 15 0.00".

B. Video Transmission

At this stage, the video trace was fed to the IEEE 802.11n simulators [11-12]. Figure 3 shows an overall of network topology. There is one base station (BS) together with various types of senders and receivers' nodes (Ns), i.e., Constant Bit Rate (CBR) and video transmission nodes. Note that at senders, the wired link is connected through BS with 1 Gbps in capacity. Table 1 also shows the detailed configuration [12, 18].

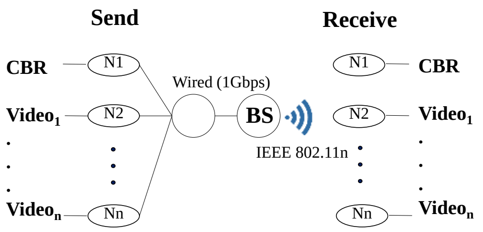

Figure 3: Network topology

Table 1
Network configuration

Type	Parameter Detail
Simulation Area	500 × 500
Simulation time	30 seconds
Node mobility	Dynamic
Bandwidth	96 Mbps
MAC layer	802.11n
Video packet size	1052 bytes
CBR data rate	37Mbs
Time slot	20 seconds
SIFS	10 seconds
TXOP limit	3.264 milliseconds
Antenna Type	Omni directional
Network Interface Type	Wireless/Physical/MIMO
Interface Queue Type	Aggregation queue
Aggregation Size	65535
Number of antennas	4
Transmission protocol	RTP/UDP

C. *Video Reconstruction*

After the simulation, the output trace was then generated with or without the loss of packets depending upon the traffic intensity. Again, EvalVid tool was modified to reconstruct the video using the output trace as well as its corresponding original video. For example, the sending and receiving traces including the original video were combined and generated the output video using “etmp4” [16]. It is worth noting that for each loss (packet), the traditional tool will fill “null” or blank pixels into the loss spot.

IV. Video Transmission Optimization

In the previous section, detailed methodology used for evaluating video transmission over IEEE 802.11n was discussed. However, it is noticeable that the traditional transmission results in low transmission efficiency with the impact of video characteristics, such as large file size and unpredictable transmission period. Note that we will discuss the issues again in the performance evaluation section. Here, this research also proposes two main techniques to improve the transmission usage, i.e., Video Transmission Preprocessing and Video Reconstruction, as follows.

A. *Video Transmission Preprocessing*

This technique was performed as a pre-processing before feeding the actual video into the network. Three more steps were developed as follows:

Video Splitting: Based on our intensive simulation, it was noticeable that transmitting large packet size often leads to more numbers of packet losses. Thus, we evaluated different packet size so as to figure out a proper size by dividing RTP packets into different sizes including the consideration of the increase of overheads, i.e., the more the fragment, the higher the bandwidth required.

As a result, we evaluated the size of traditional packet against the probable fragmentation opportunity, such as with 1000 bytes, 500, 250, and 100 bytes of fragmented packets were generated corresponding to the factor of 2, 4, and 10, respectively. At the end, we measured the quality of video using PSNR as the key metric [18]; the results reported that the size of the factor of two shows the outstanding PSNR, i.e., 39.62 vs. 32.76 and 28.69, respectively.

Video Blending: Due to unique video characteristics, one of which is the un-constant bit rate transmission; in other words, the video transmission rate may be intensely fluctuated. With the receiver buffer reserved, it was noticeable that the delay even with jitter was allowed. Here, we pre-processed a set of video to smooth out the video playout, especially the peak of video transmission over multiple video packets over time periods.

Note that this approach can only be used in case that the average bandwidth of all transmitted videos should be within the maximum allowable link capacity. The actual process was applied to figure out the mean of video size over video length, and then traverse over the length in order to spot where was above or below the average. Next, similar processes were applied for the other videos. Then, we first allowed the above average video to transmit but with the trade-off by delaying another video transmission until approaching the below average (See Figure 4). Supposedly, the required bandwidth will be balanced. Note that the amount of delaying will also be based on the receiver buffer constraint.

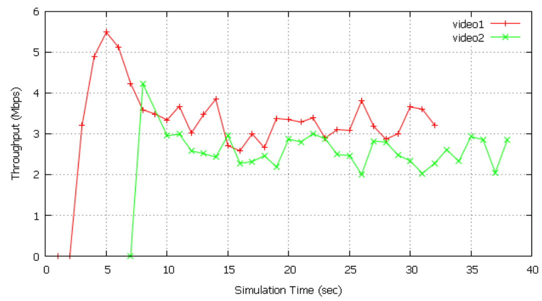

Figure 4: Example of delayed video (Blending)

Video Splitting and Blending: Given the two techniques discussed above, here is a combination of those techniques by first performing RTP packet fragmentation, and then delaying the packet according to the constraints and limitations.

B. *Video Reconstruction*

As briefly discussed, the video pre-processing techniques can improve the video transmission efficiency (See Section 5). However, it is also obvious that the loss of transmission is un-avoidable. In other words, the quality of video will be deviated given the assumption that the link capacity is limited which in fact is always true with the Internet era. Thus, due to the existing of packet loss, this research also proposes the optimized video reconstruction techniques added into the traditional EvalVid tool (etmp4) as follows.

With the loss of packets, one of the simplest ways to reconstruct the video frame is to fill the “null” or blank pixels to the particular spot. In addition, we considered four main cases based on the loss scenarios (Figure 5). It is also noted that the reconstruction process is in sequence from left to right and top to bottom; and also from Case I to IV, accordingly.

Case I: As shown in Figure 5 (left), suppose the loss is at X_1, the reconstruction is to average the front (A) and back (B) of this particular spot.

Case II: Stating in Figure 5 (right), suppose the loss is at the border of the frame, i.e., X_1, the reconstruction will be an average of the pixel of above and below this spot.

Case III: Figure 6 (left) shows an example of loss in a rectangle shape. Here, the loss of X_1 will be replaced with the average of the front and above pixels. Then, X_2 will be computed from X_1 and C, accordingly.

Case IV: In case of loss of the sequence of pixels in the borderline, Figure 6 (right) shows the replacement procedure of the use of the pixel below the missing spot. For instance, A will replace X_1; B to X_2, until E to X_5, respectively. It is worth noting that there are four borderlines, namely, top, bottom, left, and right. Thus, the operation will be similar, i.e., the replacement of the pixel one inside the video frame to its border; for instance, if the loss occurs at the bottom-line, the pixel above the bottom-line will be used as the replacement accordingly.

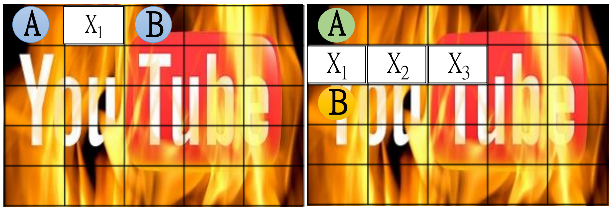

Figure 5: Loss of video transmission: examples (cases I and II).

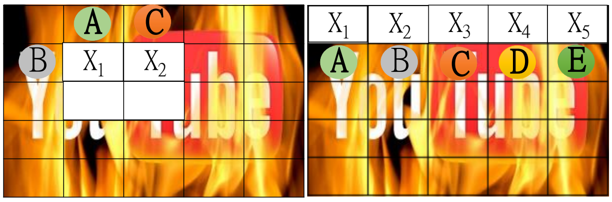

Figure 6: Loss of video transmission: examples (cases III and IV)

V. PERFORMANCE EVALUATION

In this section, the evaluation process was performed to illustrate the multi-video (YouTube) transmission over IEEE 802.11n including our video transmission optimization techniques.

A. *Simulation Setup*

To validate the video transmission performance, an NS2 baseline simulator with IEEE 802.11n modules was applied based on the recommendation provided by Wang and Wei [12] and Pokhrel et al. [18]. The simulator parameter also follows their recommendations, as briefly stated in Table 1. For example, SIF is 10 second; TXOP is 3.264 milliseconds including MIMO (4-Omni Directional Antennas) with aggregation size of 65535. Here, the network configuration follows the setup as shown in Figure 3, i.e., a single base station over multiple senders and receivers.

There are three main measurement metrics: throughput, delay, and PSNR [19]. It should be noted that PSNR was used to perceptually show the video quality perspective efficacy as stated in the equations below.

$$MSE = \frac{1}{N_{col}N_{row}}\sum_{i=0}^{N_{col}}\sum_{j=0}^{N_{row}}[S(i,j) - D(i,j)]^2 \qquad (1)$$

$$PSNR = 20\times log_{10}(255) - 10\times log_{10}(MSE) \qquad (2)$$

Here, *i* and *j* are the row and column. *S* and *D* are the matrix of original and reconstruct pixels' images. N_{col} and N_{row} denote a total number of columns and rows, respectively.

To illustrate the performance of the transmission, here, there are five main scenarios as follows.

Scenario I**:** To show the effect of multiple video transmissions, traditionally, eight videos acquired randomly from YouTube were selected for transmission over IEEE 802.11n wireless networks. The video characteristic of each video was stated in Table 2. It should be noted that the number of video frames per second is limited to 30 with 30 seconds in video length.

Table 2
Video (YouTube) characteristic (6 catagories)

Name	Type	Bit rates (kbps)
Motor Trend Channel! Drive It. Ride It. Live It.	Automotive	6892
Aston Martin DBX concept - Carbuyer at the Geneva Motor Show	Automotive	7560
Octodad Funny Moments	Gaming	6412
Ariana Grande Schools Us On Boobs	News and Politics	3393
The Balloon Gun Challenge!	Comedy	7904
Heart Ponytail Valentine's Day Hairstyles	Beauty and Fashion	4880
Furious 7 - Official Theatrical Trailer	Movie	11200
Mad Max: Fury Road – Official Main Trailer	Movie	11765

Scenario II: To show the effect of video category interaction, again, four videos acquired from YouTube were used. However, here considered only two classes, i.e., News and Politics vs. Movie, as shown in Table 3. The number of video frames per second was still fixed at 30 with 30 seconds in video length.

Table 3
Video (YouTube) characteristic (2 catagories)

Name	Type	Bit rates (kbps)
Royal Baby Leaves Hospital	News and Politics	4239
Ariana Grande Schools Us On Boobs	News and Politics	3393
Furious 7 - Official Theatrical Trailer	Movie	11200
Mad Max: Fury Road – Official Main Trailer	Movie	11765

Scenario III: Based on the evaluation of the second scenario, there was no loss since the link bandwidth was underutilized. Nevertheless, here, the generated traffic with CBR was also added so as to create the loss of video frames. The traffic was generated at the speed of 37 Mbps.

Scenario IV: To illustrate the effect of our video transmission optimization, here, first, for Splitting, similar to the previous scenario, four videos were still used with splitting technique. Second, with Blending; however, only two videos were used, and finally, with their combination, again only two videos were employed.

Scenario V: From four scenarios discussed above, there was no consideration of enhancing video reconstruction processes, i.e., only applying the blank pixel to the particular loss spot. Hence, here, we applied the optimization, and then showed the results of PSNR against the traditional ones.

B. Simulation Results and Discussions

In the first scenario, Figure 7 shows that with mixed types of videos, the highest consumed bandwidth was in category "Action" such as "Automotive and Gaming" vs. "News and Politics (videos 1 to 8), which can be concluded that a variety of video class has directly impacted the video quality, especially when there were transmitted over wireless network channels. In addition, Figure 8 shows the results from the second scenario. Here, only two classes were considered, especially to illustrate the effect of "Action" (videos 1 and 2) based videos vs. "News" (videos 3 and 4) which obviously confirmed our observation from the first scenario.

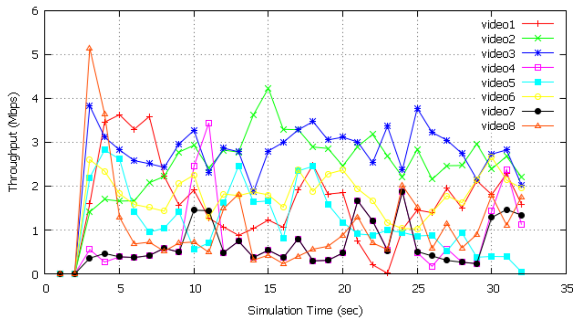

Figure 7: Throughput of video transmission (mixed video types)

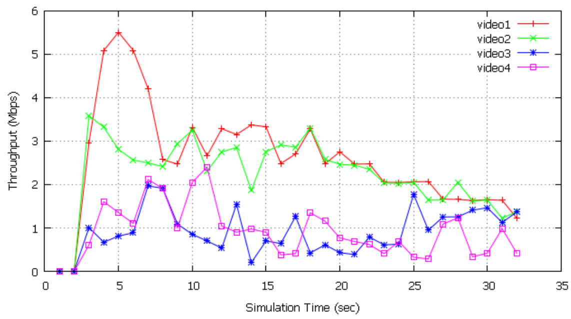

Figure 8: Throughput of video transmission (2 categories)

From the first two scenarios, there were no losses involved since the bandwidth was underutilized. The results showed the interaction among classes of videos. Nonetheless, Figure 9 shows the opposite with CBR at constant rate 37 Mbps. There were some losses here due to the peak of transmission; however, it was noticeable that at some periods of time, the total bandwidth was under-utilized.

Once considering PSNR in loss scenario, Figure 10 shows the results, and it can be concluded that PSNR of videos "Action" was substantially reduced due to high loss (the loss was occurred at the frame number 270 onward). This also applied for the other class but with a smaller factor of loss. Moreover, Figures 11 to 14 show the throughput and PSNR of the fourth scenario, i.e., Spitting, Blending, and their combination. With Splitting, Figure 11 shows that the total throughput of four videos was increased to around 38.87 Mbps, which also resulted in higher PSNR in average, i.e., 32.36, as shown in Figure 12.

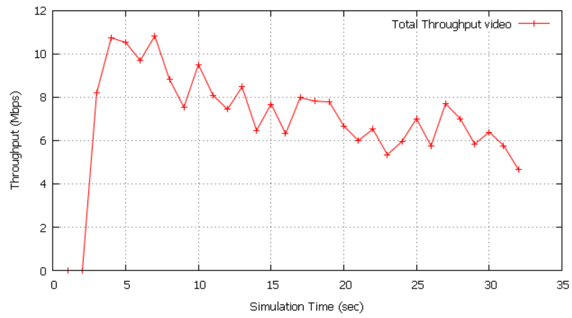

Figure 9: Throughput of video transmission (with CBR)

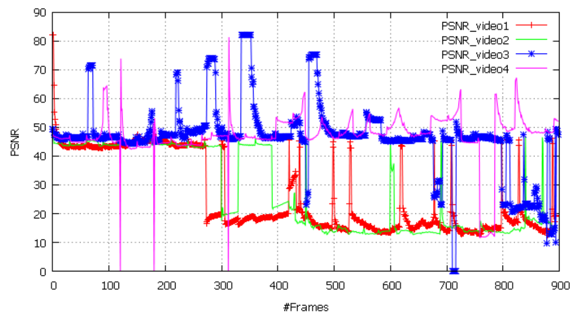

Figure 10: PSNR of video (with CBR)

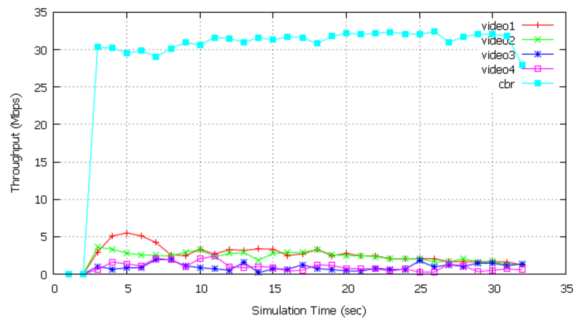

Figure 11: Throughput of video transmission (with Splitting)

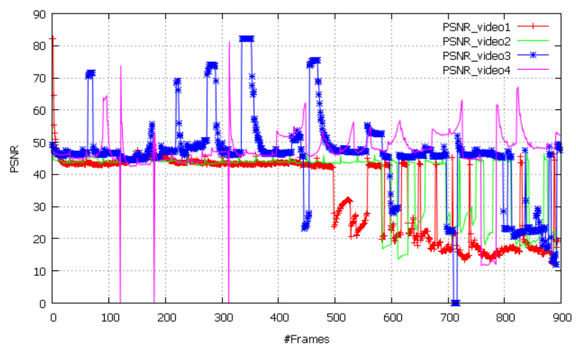

Figure 12: PSNR of video (with Spliting)

With Blending, to explicitly show the effect of delaying, here only two videos were transmitted (Action based videos) but with added CBR (the loss will be explicitly occurred). Figure 13 shows that with the delay of the second video, the loss effects can be lessen, and Figure 14 shows the increase of PSNR to 34.48 as in average. It should be noted that with this technique, the delay was increased as trade-off, and here, in average, the delay was around 0.58 second vs. only 0.02 second of the only Splitting. It is worth noting that with the combination (Splitting and Blending), similarly, the transmission performance was improved, i.e., an average PSNR of 36.78 but with only 0.45 second in delay.

Considering the final scenario with regard to video reconstruction performance, Table 4 shows an average PSNR of traditional video reconstruction versus our optimization applying into our three video pre-processing techniques. In general, with our optimization, PSNRs were higher for all techniques, i.e., 37.51 vs. 34.54 as in average. It is also noticeable that the combination of Splitting and Blending yields the highest PSNR, i.e., 39.84 and 36.78, even with or without the reconstruction optimization, respectively.

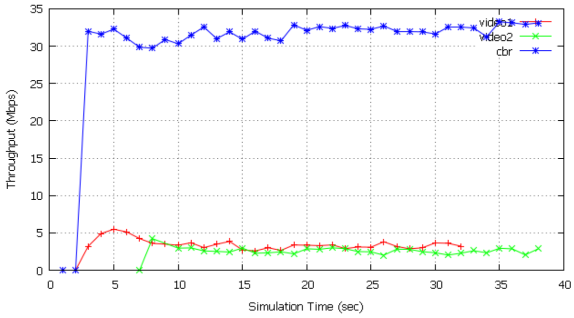

Figure 13: Throughput of video transmission (with Blending)

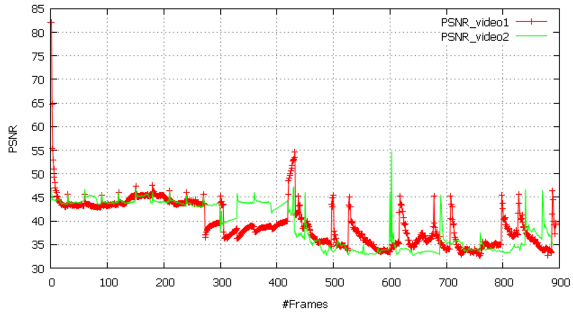

Figure 14: PSNR of video (with Blending)

Table 4
Video reconstruction performance (PSNR)

Techniques	Average PSNR	Average PSNR (Optimized)
Splitting	32.36	35.18
Blending	34.48	37.53
Splitting and Blending	36.78	39.84
Average	34.54	37.51

VI. Conclusion and Future Work

The era of Internet multimedia has brought the intensive increase of videos, i.e., YouTube, and this also leads to Internet congestion which then results in low quality of video transmissions, especially when is accessible to mobile and wireless devices. Thus, this research investigates video transmission characteristics over IEEE 802.11n in terms of throughput, delay, and PSNR, and then showed the characteristic of video category.

In addition, this research evaluated the performance of video pre-processing and video reconstruction techniques in order to improve the transmission performance, i.e., Splitting and Blending including the optimized reconstruction. The results of these enhancements are promising, i.e., the increase of PSNR from 32.36 to 36.78; 35.18 to 39.84 with our pre-processing technique; and from 34.54 to 37.51 with the reconstruction process.

It should be noted that the comparative results discussed and analyzed in this paper can be used as the baseline knowhow for further investigation in video transmission over wireless channels. However, more analyses should be well investigated, i.e., intensive evaluation of massive video transmissions, heterogeneous traffic types, variety of network configurations and topologies, and different measurement metrics in terms of human perspectives, and these are left for future work.

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